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Effects-Based Resource Planner (EBRP): Advanced Demonstration

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FOR THE COMMANDER

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This report documents the results of research activities associated with the design, development, and demonstration of the Effects-Based Resource Planner (EBRP). The overall objectives of the EBRP research effort were to demonstrate how the Cognitive Agent Architecture (Cougaar) could be applied to 1) improve the overall speed and quality of the Master Air Attack Planning (MAAP) process, 2) reduce planning (and re-planning) cycle times associated with the overall MAAP/Air Tasking Order (ATO) development process, 3) improve the confidence in MAAP supportability, and 4) reduce the workload requirements for logistics and mission planners associated with the MAAP planning process.

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PREFACE

The research documented in this technical report for the Effects-Based Resource Planner (EBRP) program sponsored by the Air Force Research Laboratory, Human Effectiveness Directorate, Logistics Readiness Branch, Wright-Patterson AFB, OH. Northrop Grumman Information Technologies, Inc. performed the work under Delivery Order #20 of the Technology for Readiness and Sustainment (TRS) contract F33615-99-D-6001. Christopher K. Curtis (AFRL/HESR) was the program manager for the effort.

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ACRONYM LIST

ACS	Air Campaign Scheduler
ALP	Advanced Logistics Project
ATO	Air Tasking Order
CAS	Combat Ammunition System
CAT	Causal Analysis Tool
Cougaar	Cognitive Agent Architecture
DARPA	Defense Advanced Research Projects Agency
DMPI	Desired Mean Point of Impact
EBO	Effects Based Operations
EBRP	Effects-Based Resource Planner
J/CAOC	Joint/Combined Air Operations Center
JFACC	Joint Forces Air Component Commander
JFC	Joint Forces Commander
JIPTL	Joint Integrated Prioritized Target List
JTT	Joint Targeting Toolkit
MAAP	Master Air Attack Plan
Pd	Probability of Damage
TPW	Target Planning Worksheet
USAF	United States Air Force
WS	Weaponeering Solution

Effects-Based Resource Planner (EBRP) Advanced Demonstration Final Report

1.0 Purpose

This report documents the results of research conducted under Delivery Order #20 of the Technology for Readiness and Sustainment (TRS) contract (F33615-99-D-6001) supporting the design, development and demonstration of the Effects-Based Resource Planner (EBRP). The period of performance for this research extended from 21 Mar 02 through 21 Mar 03.

2.0 Objective

The primary objective of the EBRP research effort was to demonstrate the feasibility of using Cognitive Agent Architecture (Cougaar) software agents to support mission planners in a Joint/Combined Air Operations Center (J/CAOC) to effectively allocate aircraft and munitions resources to targets as part of the development of a Master Air Attack Plan (MAAP). This research also supported the AFRL Effects Based Operation (EBO) Cross-Thrust Demonstration, which is also addressed in this report. The goals of the EBRP research were to show how Cougaar could be applied to 1) improve the overall speed and quality of the Master Air Attack Plan (MAAP) planning process, 2) reduce planning (and re-planning) cycle times associated with the Air Tasking Order (ATO) development process, 3) improve the confidence in MAAP supportability, and 4) reduce the workload requirements for logistics and mission planners associated with the MAAP planning process.

3.0 Introduction

3.1 Joint Air Tasking Order (ATO) Cycle

The EBRP research specifically addresses the MAAP planning process which is part of the overall joint Air Tasking Order (ATO) cycle discussed in Joint Publication 3-56.1 [1], *Command and Control for Joint Operations.* In simplest terms, an ATO represents a Joint Force Air Component Commander's (JFACC) detailed plan for employing airpower against a prioritized list of targets. The generation of an ATO is step-by-step process where each step in the process results in the generation of data and information that supports subsequent

steps in the ATO process (e.g. the identification and selection of targets supports the development of weaponeering solutions). Figure 1 identifies the six primary phases of the joint ATO planning and execution cycle. These phases include JFC/Component Coordination, Target Development, Weaponeering and Allocation, Combined ATO Development, Force Execution, and Combat Assessment. The specific tasks performed in each of these phases are discussed in more detail in Joint Publication 3-56.1, as well as the *EBRP Concept Paper* [2]. The intent in this report is to provide a general overview of the specific part of the ATO process addressed by the EBRP research, namely the development of a MAAP produced during the Weaponeering and Allocation phase of the joint ATO cycle.

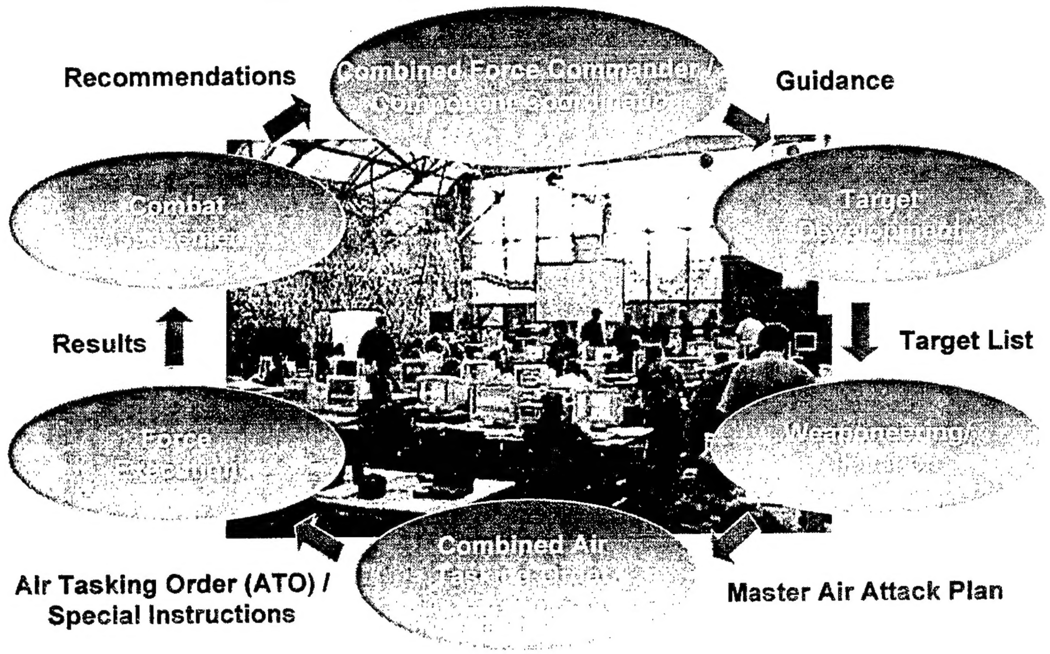


Figure 1. Air Tasking Order (ATO) Cycle

3.2 EBRP Support for the MAAP Process

The MAAP planning process is one of the most complex, and time-consuming activities in the ATO process. Currently, the MAAP planning process can take up to 12 hours to accomplish [1] and involves significant planning and coordination between targeting, operations, and support personnel who work together to build composite force packages. The planning and coordination process includes consideration for the number of available resources, including aircraft and munitions, ingress and egress routes to targets, enemy air defenses, re-fueling requirements, airspace coordination, etc. One very important task in the MAAP process is to determine how to efficiently and effectively allocate the use of available aircraft sorties and munitions assets to service targets identified in a Joint

Integrated Prioritized Target List (JIPTL). A JIPTL is a prioritized list of targets that provides identification, location, and "weaponeering" information for targets. This information is specified at a "Desired Mean Point of Impact (DMPI)" level for each target. Figure 2 is intended to help convey the relationship between targets and DMPIs. A target is uniquely identified by a "BE number". In this example, the BE number "0992-00107" refers to "Hamilton Airfield". This target has multiple DMPIs, which in this case are represented by facilities and areas on Hamilton Airfield (e.g. "Runway"). For each DMPI, one or more "weaponeering solutions" are specified (typically three to five). A weaponeering solution for a particular DMPI specifies the 1) Aircraft Type and Quantity, 2) Munition Type and Quantity, and 3) Probability of Damage (Pd) value.

TARGET NAME	BE#/UNIT ID	TGT COORD	DMPI ID	DMPI DESCRIPTION	DMPI COORD
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00546	RUNWAY	380300000N1223000000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00547	TAXIWAY	380300000N1222954000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00548	PARKING APRON	380254000N1222954000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00549	DISPERSAL AREAS	380254000N1223006000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00550	DISPERSAL AREAS	380300000N1222948000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00551	DISPERSAL AREAS	380306000N1223000000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00552	DISPERSAL AREAS	380312000N1223000000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00553	MAINTENANCE FACILITIES	380306000N1223006000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00554	MAINTENANCE FACILITIES	380300000N1223006000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00555	AMMO STORAGE	380312000N1223006000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00556	AMMO STORAGE	380254000N1222948000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00557	POL STORAGE	380254000N1223000000W
HAMILTON AFLD	0992-00107	380259990N1223000000W	E00558	POL STORAGE	380306000N1223006000W

Figure 2. Relationship between Targets and DMPIs

The JIPTL produced for a typical ATO typically contains hundreds of targets with multiple DMPIs and weaponeering solutions associated with each target. The challenge for MAAP planners is to "effectively" allocate resources located at units supporting the operation to these targets in a timely manner to support the production of the MAAP and ultimately the ATO. Currently, MAAP planners derive estimates of the total number of sorties (by aircraft type) and munitions available for allocation to targets specified on the JIPTL and then manually assign targets to units. EBRP addresses this challenge by providing MAAP planners with an automated capability to generate recommended solutions for allocating aircraft and munition resources to targets specified in a JIPTL. The solutions produced by EBRP are intended to provide a baseline for more detailed mission planning (e.g. assignment of call signs) documented on Target Planning Worksheets (TPWs). Some of the proposed benefits of EBRP include the capability to:

- Provide MAAP planners a means to evaluate one proposed solution over another. For example, two candidate logistically feasible solutions could be presented that

have essentially the same aggregate "probability of damage" (Pd) value, but one of the solutions could be much more cost effective. Currently, the MAAP planner does not have enough time to be concerned with this type of tradeoff consideration.

- Reduce the number of ATO taskings units receive that cannot be supported by available resources.
- Reduce the amount of time required to produce a MAAP and ATO, which in-turn could give the units more time to prepare for their missions, including the time to build-up munitions.
- Bridge the gap between operations and logistics planning processes. In this case, EBRP brings intrinsic consideration for the availability of resources into the mission planning process.

3.3 Cougaar

The EBRP demonstration is based on an application of the Cougaar open-source software (www.cougaar.org). The Cougaar software was developed through the Defense Advanced Research Projects Agency (DARPA) Advanced Logistics Project (ALP). Cougaar is an agent-based architecture intended to support the design and development of large-scale, distributed systems represented in terms of an "agent society". The architecture consists of building blocks of 100% Java-based software entities called "agents" that are intended to represent real-world entities such as organizations or humans and their associated business processes. Cougaar "agents" derive their specific behavior and capabilities through "plugins" [3], which encapsulate the specific business rules or decision processes of an agent. One of the interesting features of Cougaar is that it extends agent technology through the implementation of a cognitive model that attempts to capture in software how humans solve problems, particularly with respect to decomposing a task into subtasks that can then be delegated to other agents. This is a key attribute of Cougaar that was exploited during the EBRP research effort to capture and model the business rules and decision processes used by MAAP planners to allocate resources to targets.

4.0 EBRP Concept of Operations

Figure 3 provides a top-level overview of the EBRP concept of operations. In general, EBRP takes the planned targeting and resource information for a particular ATO planning

period, and based on a MAAP planner's preferences or goals, uses Cougaar agents to search and provide a proposed solution for allocating available resources to targets for each "wave" for a particular ATO planning cycle. The solution is expressed at the DMPI level for each target and includes the recommended unit, aircraft type, and weaponeering solution selected by EBRP.

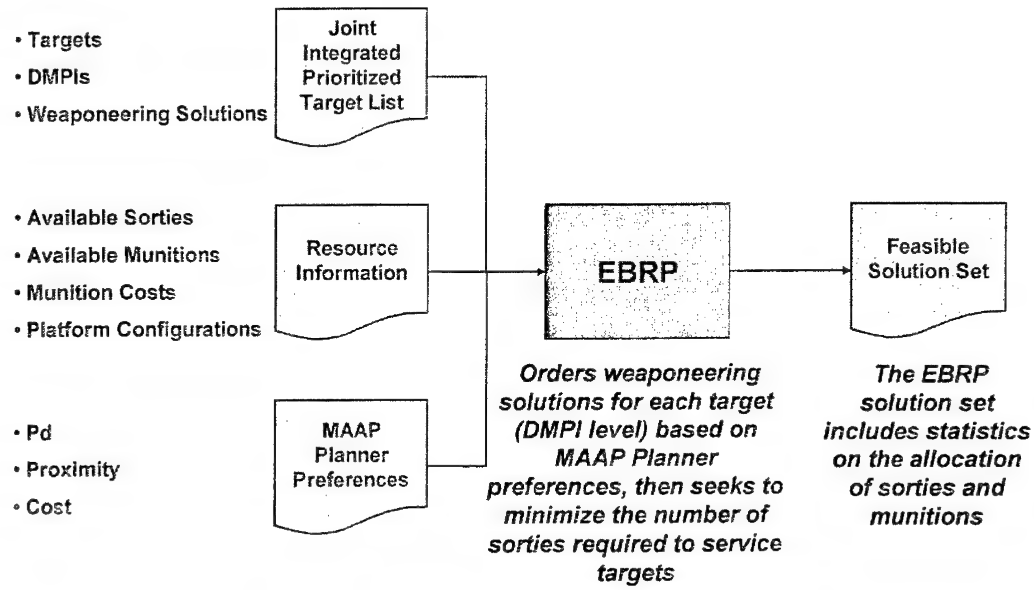


Figure 3. EBRP Concept of Operations

4.1 EBRP Inputs

The EBRP concept is based on three distinct types of inputs. These inputs include targeting information, resource information, and preferences or goals specified by MAAP Planners. The targeting information used by EBRP includes a prioritized list of targets that are "weaponeered" at the DMPI level. This type of information is included in a JIPTL produced by applications such as the Joint Targeting Tool (JTT). The resource information used by EBRP is currently restricted to aircraft and munitions. For aircraft, this includes the type aircraft, assigned unit, quantity of aircraft, and the number of available sorties by aircraft type and unit for each "wave" period associated with a particular ATO. Typically, the number of available sorties during an ATO period is specified in terms of a "contract" between a unit and the AOC, and is usually some quantity less than the number of possessed aircraft at a given unit. For munitions, EBRP uses both cost and inventory information. Cost information is based on the "complete round cost" of a particular munition and was obtained from a report generated by the Combat Ammunition System (CAS). The munitions inventory information used for the EBRP demonstration is based on data for locations (bases)

contained in the "Pacifica" data set used to support JEFX 2000. The particular locations from the Pacifica data set used for the EBRP demonstration are discussed in the next section.

4.2 MAAP Planner Preferences

The preferences (goals) specified by a MAAP planner in EBRP provide constraints that are used by the Cougaar agents to order the weaponeering solutions provided for each target at the DMPI level. This ordering specifies the manner in which EBRP agents will search to source the resources necessary to satisfy weaponeering solutions specified for each DMPI associated with a target. Currently, the EBRP demonstration supports three specific types of preferences, including:

- Maximizing the probability of damage (Pd),
- Minimizing the distance to target (proximity),
- Minimizing the cost of munitions (cost).

The MAAP planner can specify the selection (non-selection) and order of these preferences. If the MAAP planner elects not to select and order preferences, EBRP reverts to a default precedence order of Pd, proximity, and cost to order weaponeering solutions. In this case giving the largest weight to Pd, then proximity of units, and finally, munitions cost.

Let's look at a simple example to see how these preferences are applied in EBRP. When a target list is initially imported into EBRP, it creates an internal matrix representation of all targets and their respective weaponeering solutions at the DMPI level similar to the matrix shown in Table 1. The rows in the matrix represent target DMPIs (e.g. "D1") and the columns represent the alternative weaponeering solutions associated with each DMPI (e.g. "WS1"). At this point, the weaponeering solutions appearing in each column are not ordered in any specific manner, and are listed from left to right in the order each solution appeared in the input target list.

D1	WS1 (80%)	WS2 (70%)	WS3 (80%)	WS4 (90%)	WS5 (75%)
D2	WS1 (70%)	WS2 (80%)	WS3 (90%)	WS4 (95%)	WS5 (85%)
D3	WS1 (90%)	WS2 (80%)	WS3 (85%)	WS4 (90%)	WS5 (75%)

Table 1. Initial Matrix Representation of a Target List

Once the target list is imported and the initial matrix is constructed, EBRP looks at the weaponeering solution for each DMPI and "attaches" the candidate unit(s) available that

could potentially satisfy the aircraft and munition resources specified as part of each weaponeering solution (e.g. 2-F16C each configured with 2-AGM154). For example, referring to DMPI "D1" in Table 2, we see that only Unit 1 ("U1") has the resources (aircraft and munitions) identified that could potentially satisfy the weaponeering solution specified for "WS1", so this unit is attached as a potential candidate unit to the weaponeering solution "WS1" to service DMPI "D1". Each weaponeering solution will typically have one or more units attached as part of the weaponeering solution, however in some cases, there may not be a unit that can satisfy the type aircraft and/or munition specified in a weaponeering solution. In this case, EBRP ignores the weaponeering solution completely and no unit is "attached". A revised matrix example with unit "attachments" is shown in Table 2.

D1	WS1 (80%) U1	WS2 (70%) U1,U2	WS3 (80%) U1	WS4 (90%)	WS5 (75%) U2
D2	WS1 (70%)	WS2 (80%) U2,U3	WS3 (90%) U2	WS4 (95%) U3	WS5 (85%) U1,U2
D3	WS1 (90%) U2	WS2 (80%) U2	WS3 (85%) U2,U3	WS4 (90%) U1,U2,U3	WS5 (75%)

Table 2. Matrix Representation of a Target List – Units "Attached"

The final re-ordering steps of the target-weaponeering matrix are based on the specific preferences specified by the MAAP planner. For instance, assume that the default preference order described earlier (i.e. Pd, proximity, cost) is selected by the MAAP planner. In this case, EBRP would internally re-sort the matrix in Table 2 first on Pd values, then based on the proximity of units to targets, and finally on the cost of munitions associated with a weaponeering solution. Let's examine each of these steps.

First, EBRP will re-order the weaponeering solutions specified for each DMPI from left to right (largest to smallest) based on the Pd values specified for each weaponeering solution. The results of this step are shown in Table 3. Note that in some cases the Pd values associated with the weaponeering solutions for a particular DMPI may be the same. In this case, additional re-ordering of the matrix based on proximity and cost preferences will resolve this tie and determine the final ordering of weaponeering solutions in the matrix that EBRP will use to derive a solution set.

D1	WS4 (90%)	WS1 (80%) U1	WS3 (80%) U1	WS5 (75%) U2	WS2 (70%) U1,U2
D2	WS4 (95%) U3	WS3 (90%) U2	WS5 (85%) U1,U2	WS2 (80%) U2,U3	WS1 (70%)
D3	WS1 (90%) U2	WS4 (90%) U1,U2,U3	WS3 (85%) U2,U3	WS2 (80%) U2	WS5 (75%)

Table 3. Re-ordered Matrix Based on Pd Values

In the next step, EBRP will re-order weaponeering solutions for each DMPI in Table 3 based on the proximity of the candidate units "attached" to each weaponeering solution (distance from a unit to the DMPI). The results of this re-ordering are displayed in Table 4. In those cases where there is more than one candidate unit "attached" to a weaponeering solution for a DMPI, assume that the unit listed first has the closest proximity to the DMPI. For example, referring to Table 4, the candidate units to service DMPI "D1" using weaponeering solution "WS2" are units "U2" and "U1" respectively. Since unit "U2 is listed first, we conclude that unit "U2" is closer in proximity to DMPI "D1" than unit "U1".

D1	WS4 (90%)	WS1 (80%) U1	WS3 (80%) U1	WS5 (75%) U2	WS2 (70%) U2,U1
D2	WS4 (95%) U3	WS3 (90%) U2	WS5 (85%) U2,U1	WS2 (80%) U2,U3	WS1 (70%)
D3	WS1 (90%) U2	WS4 (90%) U2,U1,U3	WS3 (85%) U2,U3	WS2 (80%) U2	WS5 (75%)

Table 4. Re-ordered Matrix Based on Proximity

The final step in the EBRP reordering process is based on the cost of munitions specified as part of each weaponeering solution. This cost is based on the complete round cost for the munition(s) specified for a particular weaponeering solution. For discussion purposes here, assume the cost of "WS1" > "WS2" > "WS3" > "WS4" > "WS5". The results of this final re-ordering step are portrayed in Table 5. Note that the application of the cost preference in the final re-ordering step serves only to potentially break ties between adjacent weaponeering solutions that have equivalent Pd values and also the same units "attached" to the weaponeering solution. The cells of the matrix affected by this re-ordering step are highlighted in Table 5.

D1	WS4 (90%)	WS3 (80%) U1	WS1 (80%) U1	WS5 (75%) U2	WS2 (70%) U2,U1
D2	WS4 (95%) U3	WS3 (90%) U2	WS5 (85%) U2,U1	WS2 (80%) U2,U3	WS1 (70%)
D3	WS4 (90%) U2,U1,U3	WS1 (90%) U2	WS3 (85%) U2,U3	WS2 (80%) U2	WS5 (75%)

Table 5. Re-ordered Matrix Based on Cost

4.3 EBRP Solution Process

Once the re-ordering of the weaponeering solutions in the target list is completed based on the preferences specified by the MAAP planner, the EBRP solution process begins. During this process, EBRP traverses the prioritized target list (at the DMPI level) from top to bottom attempting to source aircraft and munition resources from units "attached" to weaponeering solutions for each DMPI in the final, re-ordered matrix. For example, referring to DMPI "D1" in Table 5, EBRP would ignore the first weaponeering solution "WS4" since no unit is attached, and move to weaponeering solution "WS3", attempting to source the munitions and aircraft sorties specified for "WS3" from unit "U1". This process continues at the DMPI level for each target in the imported target list. Upon completion, EBRP reports back to the MAAP planner with a solution set that identifies a proposed weaponeering solution and unit for all DMPIs in the target list that could be satisfied based on the availability of munition resources and sorties for the ATO planning period. So, based on the availability of munitions and sorties, it is possible that not all DMPIs in a particular target list will be satisfied. EBRP provides both summary level and detailed reports on the proposed allocation of sortie and munition resources, as well as statistics on target coverage at the DMPI level. It is important to note that the focus of the EBRP demonstration currently attempts to find a solution constrained only by the availability aircraft and munitions. In reality there are many other factors that could affect the possible solution. Some of these factors include weather conditions, personnel availability, fuel availability, and refueling tanker availability. These factors would need to be addressed in a full implementation of the EBRP concept.

5.0 EBRP Technical Design

5.1 EBRP Agent Society

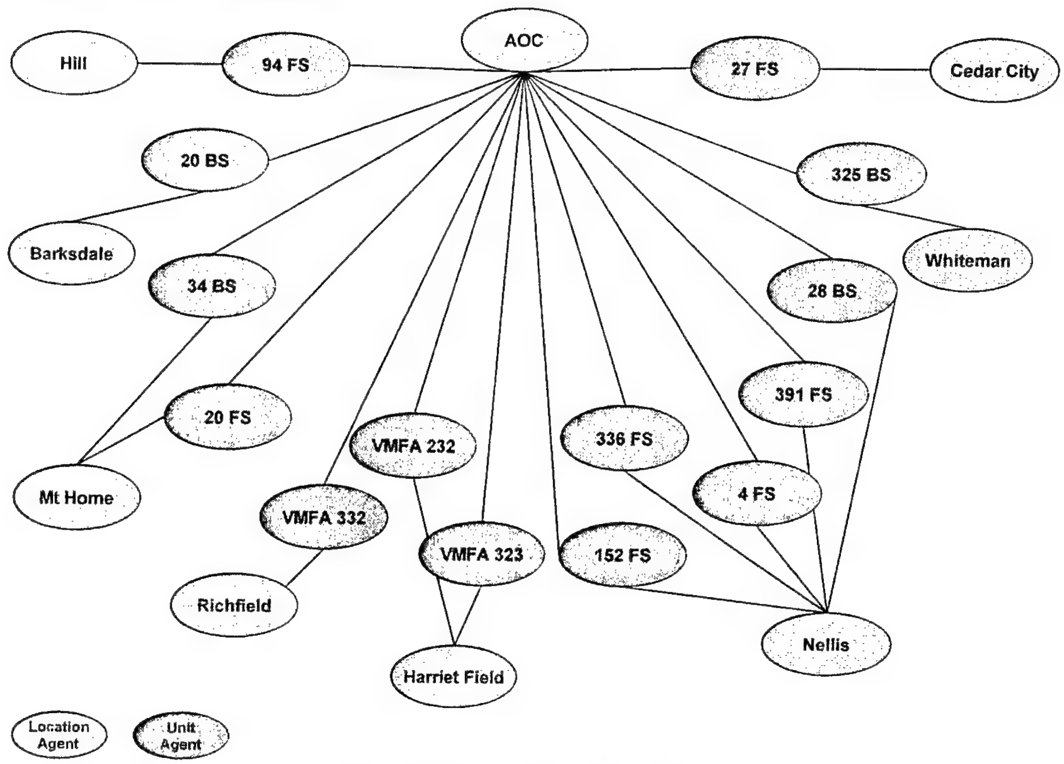


Figure 4. EBRP Agent Society

Figure 4 portrays the Cougaar agent society designed and implemented specifically for the EBRP demonstration. There are two main classes of Cougaar agents in the EBRP society, for discussion purposes these agents are labeled in Figure 4 as "location" agents and "unit" agents. Location agents represent the beddown or operating locations in the EBRP agent society (e.g. "Nellis"). The primary assets owned by the location agents include the munition inventories at each operating location. The unit agents represent the flying squadrons or units at each operating location (e.g. "152FS"). The solid lines between agents are intended to depict the relationship between agents in the EBRP society. For instance, unit agents own aircraft resources that contribute sorties to an operation and communicate directly with the "AOC" agent. The AOC agent makes requests to unit agents for aircraft and munition resources to satisfy a particular weaponeering solution. Since munitions at a given location support the various units and aircraft assigned to that location, the munitions portion of this request is communicated by the unit agent to the location agent responsible for management of munition inventories at a respective location. The success (or failure) by the location agent to satisfy the request for munitions is reported back to the unit agent and in-

turn, to the AOC agent. This scheme is used by the EBRP agents to address each DMPI in the imported target list and derive the overall solution set proposed by EBRP.

It is important to note that the specific location and unit designations (e.g. "Nellis") used to construct the EBRP agent society shown in Figure 4 are based on a subset of units and locations from the "Pacifica" data set which is also being used to support research for the AFRL EBO program and associated EBO Cross-Thrust Demonstration. The Pacifica data used for the EBRP research is included in Appendix 1.

5.2 EBRP Assumptions

The following assumptions apply to the design and development of the EBRP demonstration software. These assumptions are based in part on information gathered during the discussions with MAAP planner personnel and the review of current munitions operating policies and directives.

a. There are no restrictions on the number of "waves" that can be specified for a particular ATO cycle.

b. Only strike aircraft (i.e. fighter and bomber aircraft) specified as part of a weaponeering solution in the JIPTL are addressed by EBRP. No support aircraft (e.g. aerial re-fueling, reconnaissance, etc.) were addressed in the EBRP demonstration.

c. Fighter aircraft are only tasked to service one target (equivalent to the Basic Encyclopedia reference number), but can service multiple DMPIs associated with a target.

d. Bomber aircraft can service multiple targets and DMPIs.

e. The default preference profile for the ordering of weaponeering solutions is based on 1) platform/weapon effectiveness expressed in terms of Pd, 2) proximity of operating units with the right resources to a respective target, and 3) resource cost (e.g. cost of weapons).

f. In configuring aircraft with weapons, EBRP will not exceed the Standard Conventional Load (SCL) parameters designated for a particular aircraft.

g. Aircraft can be configured to less than an SCL configuration.

h. Unit integrity is preserved when searching for a solution. This means that aircraft and munitions specified for a particular weaponeering solution must be sourced from the same unit (for aircraft) and location (for munitions).

6.0 EBRP Demonstration Software

This section discusses the process for executing the EBRP demonstration software. The intent is to highlight and explain the key steps a MAAP planner would follow to run the EBRP demonstration software and produce a proposed solution set for allocating strike aircraft and munition resources to targets. For discussion purposes, let's assume the EBRP demonstration software has been installed on a PC and a MAAP planner has launched the EBRP application. This starts the EBRP agent society, initializes aircraft and munition resources at each unit and location, and generates the input screen to allow a MAAP planner to specify a target list for import.

6.1 Import Targets

The input screen supporting the import of a target list is shown in Figure 5. The MAAP planner would select an integrated and prioritized target list generated for a specific ATO (i.e. a JIPTL) and import the target list into EBRP. Once the target list is selected and imported, EBRP displays the targets on a map such as the one portrayed in Figure 6. The EBRP demonstration currently supports the display of targets (not DMPIs) and units only. Dragging the mouse cursor over a target will provide a target nomenclature or description.

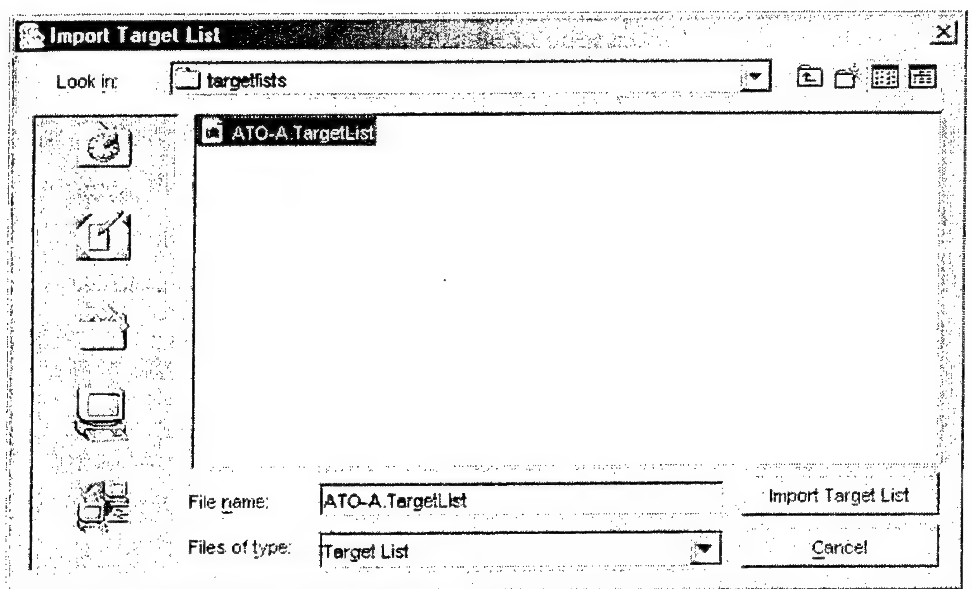


Figure 5. User Interface for Target List Import

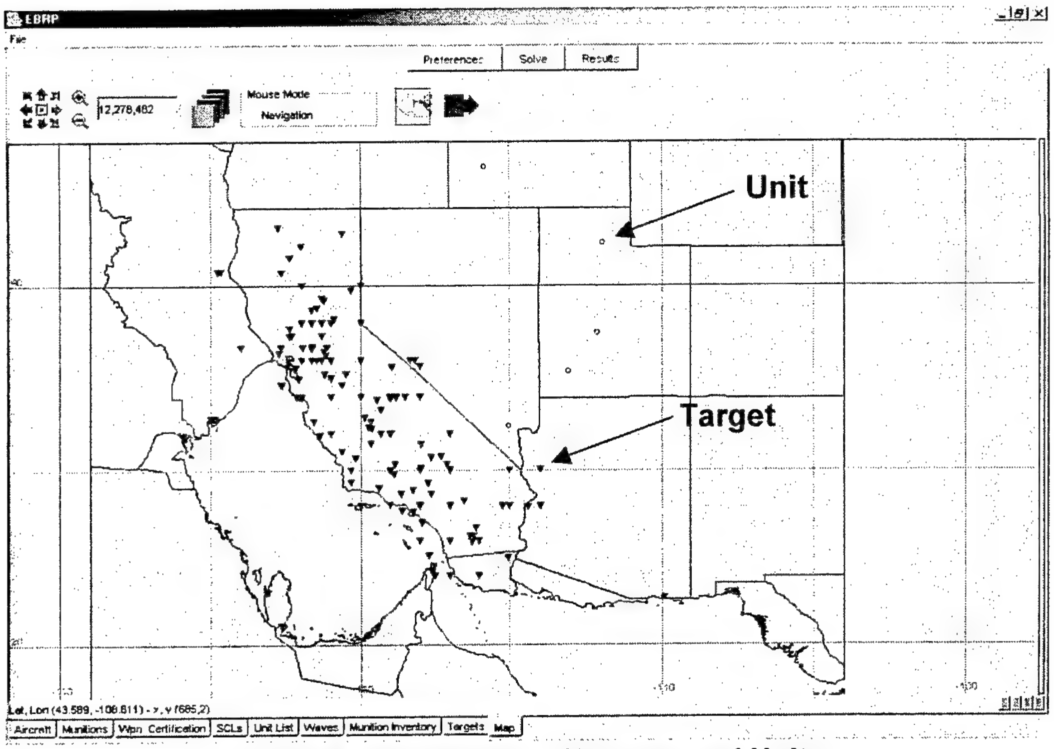
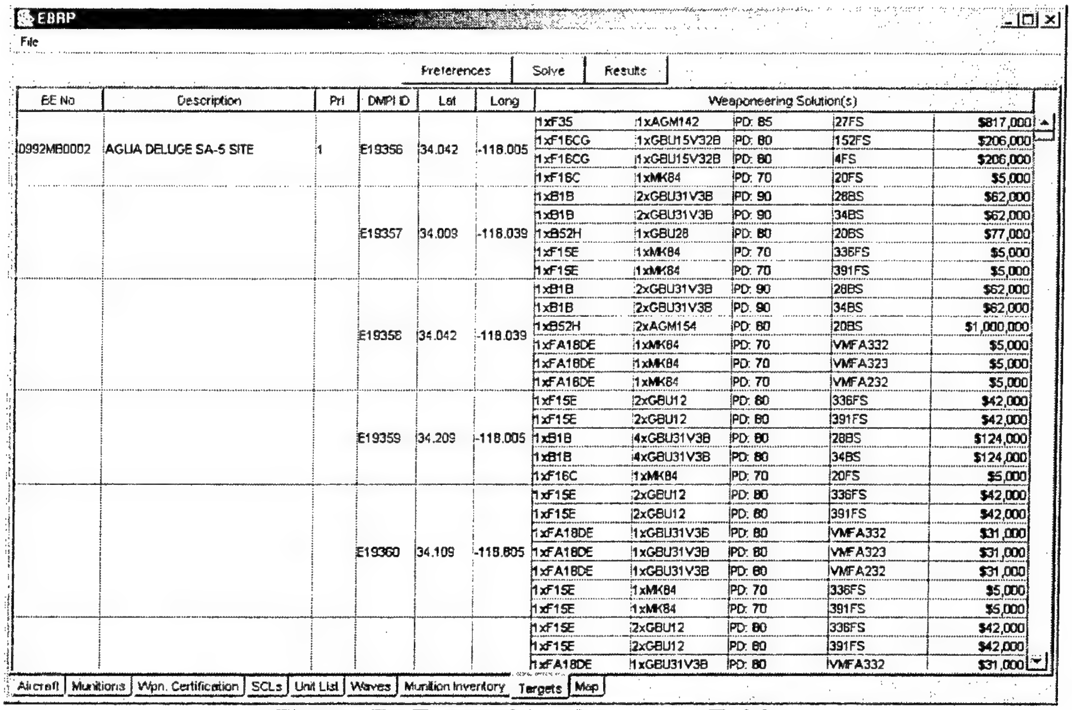


Figure 6. Map Display of Targets and Units

As part of the import process, EBRP also generates a summary of all targets at the DMPI level and there associated weaponeering solutions (see Figure 7). Notice that the weaponeering solutions for each DMPI are initially ordered in the summary table based on the default preference profile used by EBRP. This profile initially orders the imported weaponeering solutions for each target-DMPI combinations based on Pd value, proximity, and cost. For example, Figure 7 displays the "DMPI ID" for all DMPIs associated with the target "Agua Deluge SA-5 Site". This target is uniquely identified by the BE Number "0992MB0002". In addition, all DMPIs (see "DMPI ID" column) for this target are also identified along with their associated weaponeering solutions. EBRP looks at each weaponeering solution and attaches a unit(s) that could satisfy the aircraft and munition requirements specified by the weaponeering solution. The solutions are then initially ordered by EBRP based on Pd value, proximity, and cost. This is the order EBRP agents will use to search for solutions unless the MAAP planner elects to change the preference profile.

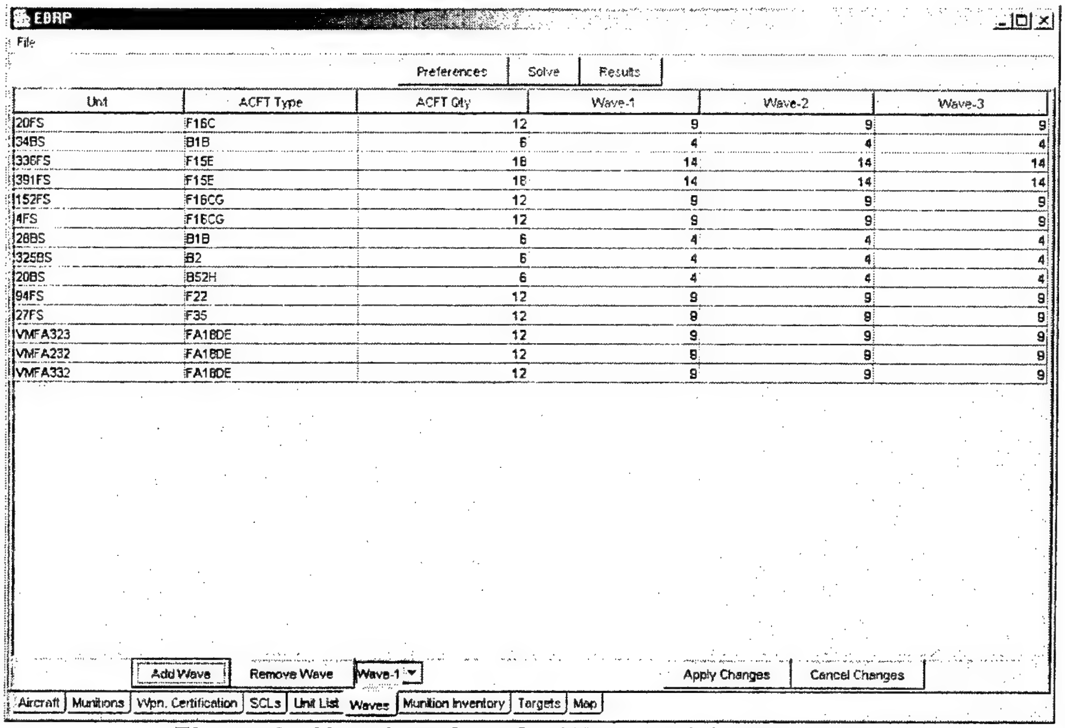


BE No	Description	Pri	DMPI ID	Lat	Long	Weaponeering Solution(s)				
0992MB0002	AGUA DELUGE SA-5 SITE	1	E19356	34.042	-118.005	1xF35	1xAGM142	PD: 85	27FS	$817,000
						1xF16CG	1xGBU15V32B	PD: 80	152FS	$206,000
						1xF16CG	1xGBU15V32B	PD: 80	4FS	$206,000
						1xF16C	1xMK84	PD: 70	20FS	$5,000
			E19357	34.009	-118.039	1xB1B	2xGBU31V3B	PD: 90	28BS	$62,000
						1xB1B	2xGBU31V3B	PD: 90	34BS	$62,000
						1xB52H	1xGBU28	PD: 80	20BS	$77,000
						1xF15E	1xMK84	PD: 70	336FS	$5,000
						1xF15E	1xMK84	PD: 70	391FS	$5,000
			E19358	34.042	-118.039	1xB1B	2xGBU31V3B	PD: 90	28BS	$62,000
						1xB1B	2xGBU31V3B	PD: 90	34BS	$62,000
						1xB52H	2xAGM154	PD: 80	20BS	$1,000,000
						1xFA18DE	1xMK84	PD: 70	VMFA332	$5,000
						1xFA18DE	1xMK84	PD: 70	VMFA323	$5,000
						1xFA18DE	1xMK84	PD: 70	VMFA232	$5,000
			E19359	34.209	-118.005	1xF15E	2xGBU12	PD: 80	336FS	$42,000
						1xF15E	2xGBU12	PD: 80	391FS	$42,000
						1xB1B	4xGBU31V3B	PD: 80	28BS	$124,000
						1xB1B	4xGBU31V3B	PD: 80	34BS	$124,000
						1xF16C	1xMK84	PD: 70	20FS	$5,000
			E19360	34.109	-118.805	1xF15E	2xGBU12	PD: 80	336FS	$42,000
						1xF15E	2xGBU12	PD: 80	391FS	$42,000
						1xFA18DE	1xGBU31V3B	PD: 80	VMFA332	$31,000
						1xFA18DE	1xGBU31V3B	PD: 80	VMFA323	$31,000
						1xFA18DE	1xGBU31V3B	PD: 80	VMFA232	$31,000
						1xF15E	1xMK84	PD: 70	336FS	$5,000
						1xF15E	1xMK84	PD: 70	391FS	$5,000
						1xF15E	2xGBU12	PD: 80	336FS	$42,000
						1xF15E	2xGBU12	PD: 80	391FS	$42,000
						1xFA18DE	1xGBU31V3B	PD: 80	VMFA332	$31,000

Figure 7. Target List Summary Table

6.2 Specify Waves and Available Sorties

Once the target list is imported, the next step for the MAAP planner is to specify the number of "waves" for the ATO period, and assign the number of available sorties that each unit will contribute to support the planned ATO. The user interface for entering wave and sortie information is depicted in Figure 8. Using the "Add Wave" button, the MAAP can add any number of waves for the ATO planning period. For each wave, EBRP initially defaults the number of sorties in each wave to 80% (rounded) of the number of aircraft assigned to each unit (see "Acft Qty" column). The default is intended to account for the fact that some number of aircraft at each unit will be designated as spares, down for maintenance, or simply not available for tasking. The MAAP planner can change the default number of sorties for a particular unit up to the number of aircraft assigned to the unit. Once all waves and sortie information is entered, the MAAP planner selects the "Apply Changes" button to save all wave and sortie information. The EBRP software also supports the selection and removal of previously entered wave and sortie information via a drop-down list. In this case, the MAAP planner selects the desired wave and selects the "Remove Wave" button. In addition, changes to wave and sortie information can be cancelled and restore to their original values.



Unit	ACFT Type	ACFT Qty	Wave-1	Wave-2	Wave-3
20FS	F16C	12	9	9	9
34BS	B1B	6	4	4	4
336FS	F15E	18	14	14	14
391FS	F15E	18	14	14	14
152FS	F16CG	12	9	9	9
4FS	F16CG	12	9	9	9
28BS	B1B	6	4	4	4
325BS	B2	6	4	4	4
20BS	B52H	6	4	4	4
94FS	F22	12	9	9	9
27FS	F35	12	9	9	9
VMFA323	FA18DE	12	9	9	9
VMFA232	FA18DE	12	9	9	9
VMFA332	FA18DE	12	9	9	9

Figure 8. User Interface for Wave and Sortie Inputs

6.3 Select Targets and Assign to Waves

At this point the MAAP planner has imported the target list, specified the number of waves for the ATP planning period, and identified the number of available sorties for each unit supporting the ATO (aircraft strike missions only). The next step for the MAAP planner is to select targets displayed on the map and assign targets to a specific wave. Through the EBRP user interface supporting the display of targets on a map (Figure 6), the MAAP planner groups targets based on factors such as the geographical location and concentration of targets, threat, etc. There is no standard process for grouping targets; hence, MAAP planners may approach the process of grouping targets differently. For this reason, EBRP supports the selection of multiple targets ("rubber band" selection) or individual targets (some targets that a MAAP Planner wants to assign to a package may fall outside the "rubber-band" region"). Targets can be selected and assigned to waves individually, or selected in groups using the "rubber banding" feature supported by EBRP. As targets are selected and assigned to a wave, EBRP will display the BE numbers for each selected target (see Figure 9). It is important to note that the selection of a target includes all DMPIs associated with a respective target. In addition, it is not necessary to select and assign all targets appearing on the map, any number can be selected and assigned to a wave.

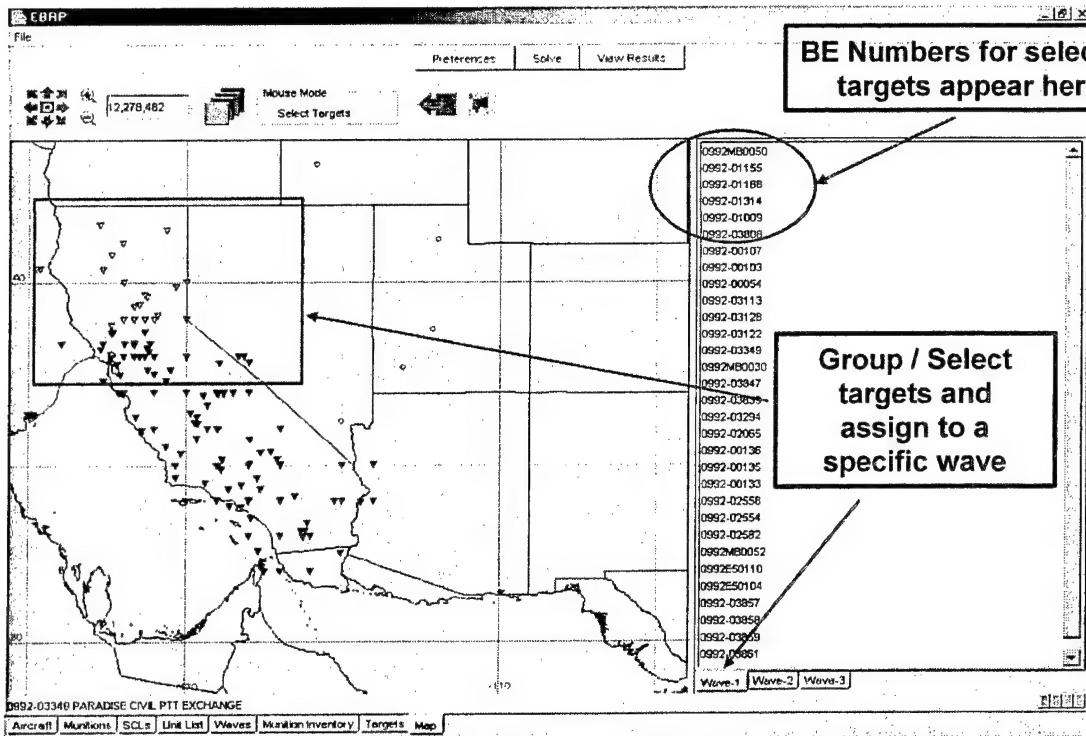


Figure 9. User Interface for Selecting and Assigning Targets to Waves

6.4 Modify Preferences

Through the user interface shown in Figure 10, the MAAP planner can review the default search preferences and select and re-order the application of preferences. As discussed earlier, preferences are used to order the weaponeering solutions specified for each target at the DMPI level. The EBRP agents search for solutions based on preferences. Referring to Figure 10, the preferences are ordered from top to bottom in order of importance - most important to least important. MAAP planners can deactivate preferences and change the order of preferences, however no new preferences can be added. In addition to re-ordering and turning on/off preferences, planners can also apply a "tolerance value" or weighting factor that is used to compare adjacent weaponeering solutions. For instance, assume the "tolerance value" for the preference "cost" is set to 10%. In this case, EBRP will compare the total munitions cost of each weaponeering solution associated with a particular DMPI, and consider adjacent weaponeering solutions equivalent (in terms of cost) if the cost of munitions for each solution is within 10% of each other. The application of "tolerance values" may or may not change the search order of weaponeering solutions associated with a particular DMPI.

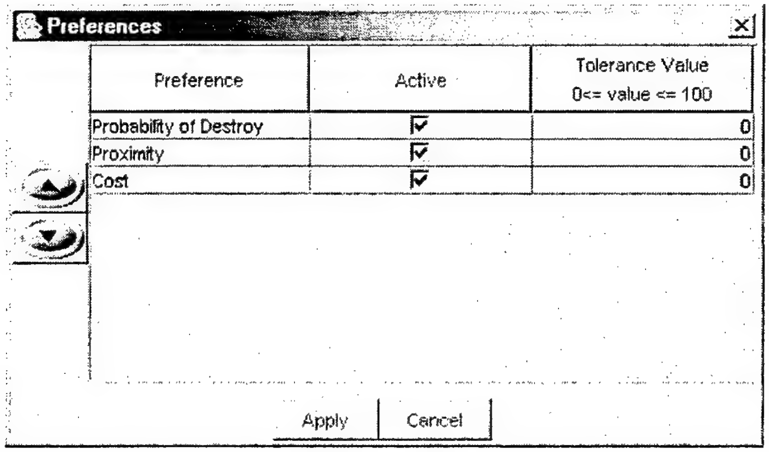


Figure 10. User Interface for Modifying Search Preferences

6.5 Generate Solution Set and Output Reports

At this point, the "problem" has been defined and it is time for EBRP to derive a feasible solution set for allocating available resources (sorties and munitions) to DMPIs in the ATO target list that was initially imported into EBRP. To generate a solution set, the MAAP planner selects the "Solve" button on the user interface shown in Figure 9. The solution process begins without any additional user intervention.

Recall that at this point the target-weaponeering solution matrix is sorted at the DMPI level for each target based on the preferences specified by the MAAP planner (or using the default preference profile previously discussed). Since the target list is already prioritized, the EBRP agents start with the first target and DMPI in the target list, and examine the first "ordered" weaponeering solution for the respective DMPI. During this step, the "AOC" agent will make a request to the "Unit" agent "attached" to the weaponeering solution to see if the "Unit" agent can support the requirements (sortie and munitions) specified in the weaponeering solution. The "Unit" agent handles the sortie part of the request, and coordinates with the respective "Location" agent where the unit is assigned to determine if the required munitions specified as part of the weaponeering solution are available. If the unit can satisfy the request, the resources are allocated internally and the success or failure of the request is reported back to the "AOC" agent. This process continues for each target in the target list until all targets have been examined. The result of this process is a proposed solution set that identifies the success or failure of EBRP in allocating sorties and munitions to targets in the target list.

Once EBRP has completed its internal processing of the target list based on the MAAP planner's preferences, and developed resource sourcing solutions for targets (some targets may not have a solution based on resource availability for the time period required), the results are displayed to the MAAP planner. The key reports generated by EBRP include a top-level summary report and detailed solution report. The summary report provides top-level statistics on the number of targets and DMPIs covered by the EBRP solution set, as well as the average Pd achieved, and total cost of the solution. A sample summary report is shown in Figure 11.

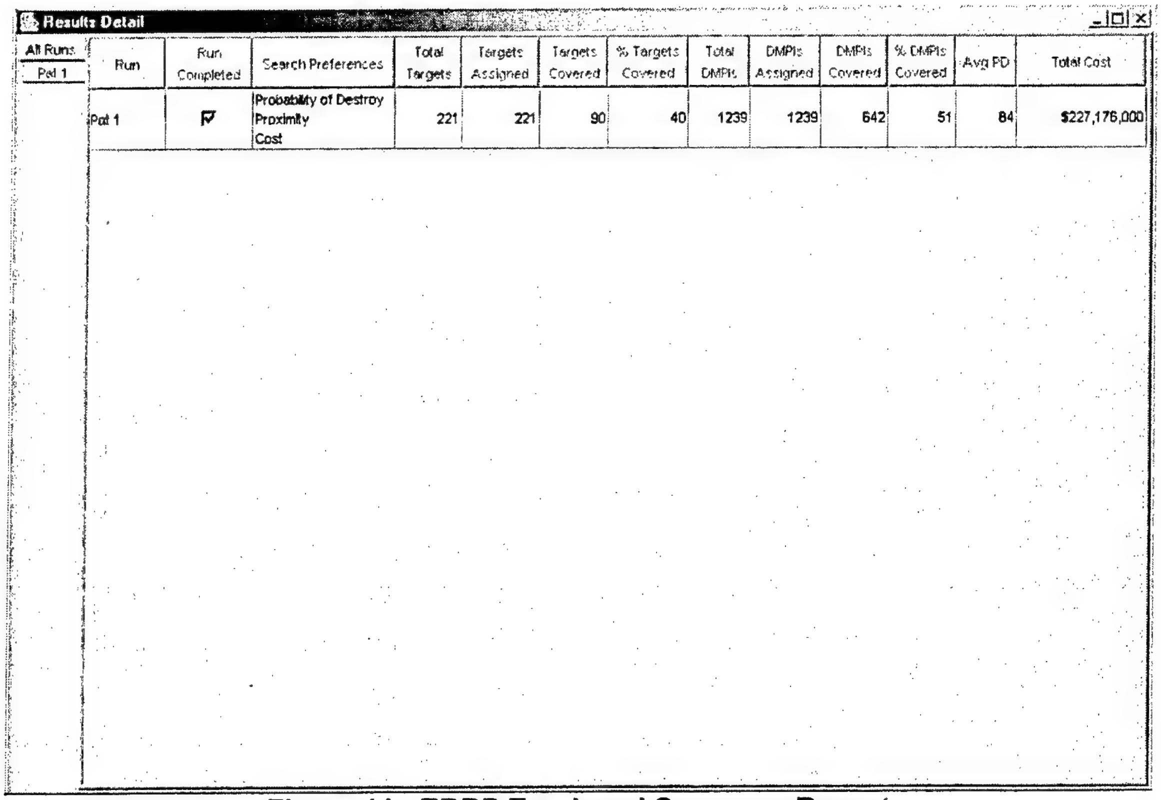


Figure 11. EBRP Top-Level Summary Report

The detailed solution report produced by EBRP as part of each solution set is depicted in Figure 12. The detailed solution report identifies the specific weaponeering solution and unit proposed for a target at the DMPI level. For those DMPIs that EBRP was able satisfy, the proposed weaponeering solution is shaded in "green". If none of the weaponeering solutions for a particular DMPI could be satisfied by EBRP, then none of the weaponeering solutions are shaded. At the target level, if all DMPIs for a target were satisfied the target BE Number is shaded in "green". If only a subset of the DMPIs for a target were satisfied, then the target BE Number is shaded in "yellow". If none of the DMPIs for a target were satisfied, then the target BE Number is not shaded.

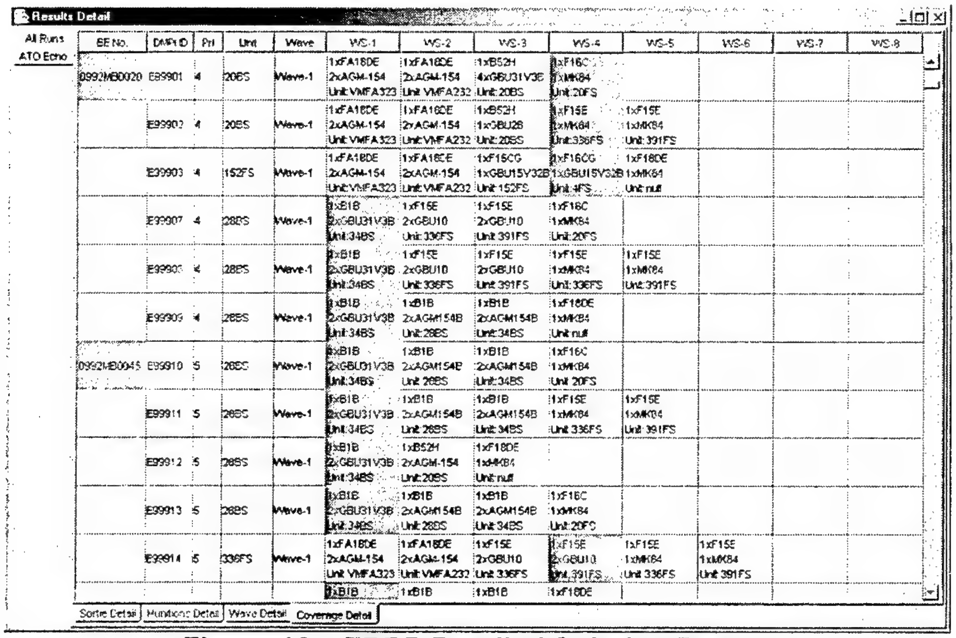


Figure 12. EBRP Detailed Solution Report

EBRP produces a variety of other reports on the allocation of sortie and munitions for each solution set or "run" to support analysis by MAAP planners. These additional reports provide detailed statistics on the allocation of sorties for each wave in the ATO period, as well as the allocation of munitions at each location. Sample output reports are included in Appendix 2.

7.0 EBRP's Role in the EBO Cross Thrust Demonstration

The AFRL/IF EBO program is focused on designing, developing, and demonstrating a suite of tools to support effects-based campaign planning. In an effort to look at the feasibility of integrating other technology efforts that could potentially enhance the effects-based planning process, AFRL/IF and AFRL/HE collaborated on an EBO cross-thrust initiative aimed at identifying, integrating and demonstrating technologies from selected research efforts. AFRL/HESR identified EBRP as a candidate research effort for participation in the EBO cross-thrust demonstration. In support of this demonstration, an interface was developed between EBRP and one of the EBO programs, the Air Campaign Scheduler (ACS) tool developed by Carnegie-Mellon University. This interface allows the ACS tool to query EBRP via an Application Programming Interface (API) and make requests for munitions needed to support the ACS process of planning and scheduling missions. In this sense, EBRP simply acts as a "manager" of munitions resources at each location. The

importing of target information and the planning and scheduling of missions is accomplished by the ACS application.

The EBRP-ACS interface process developed for the EBO Cross-Thrust demonstration is accomplished through sockets and a simple protocol scheme that is used to communicate messages (requests and responses) between EBRP and ACS. There are two types of requests that can be sent to EBRP and two types of responses that EBRP sends to the ACS tool. The requests to EBRP will consist of a QUERY request and an ALLOCATE request. EBRP responds to the QUERY request with a QUERY_RESPONSE message and responds to an ALLOCATE request with and ALLOCATE_RESPONSE message.

Figure 13 provides an overview of the ACS-EBRP and messaging scheme. For each DMPI in a target list that the ACS tool is attempting to schedule resources for, it will query EBRP to determine the inventory levels of munitions, from one or more locations (bases), for a particular point in time. EBRP responds to this request and reports the inventory information to ACS for the locations and munitions specified in the query request. The ACS tool in-turn, determines the specific allocation of munitions (including the quantity and location) and communicate an allocation request to EBRP. The allocation request identifies the munition type(s), quantity(s), and location(s) used by ACS to satisfy the weaponeering requirements specified for a particular DMPI. EBRP decrements the appropriate inventory levels based on the information in the allocation request, and then completes the cycle by sending a response to the ACS confirming the allocation. This process is repeated for each DMPI in the target list that the ACS tool is using for scheduling missions. The intent of the integration of ACS and EBRP is to demonstrate a capability for the ACS tool to have more real time insight on the availability of munitions during the sortie scheduling process.

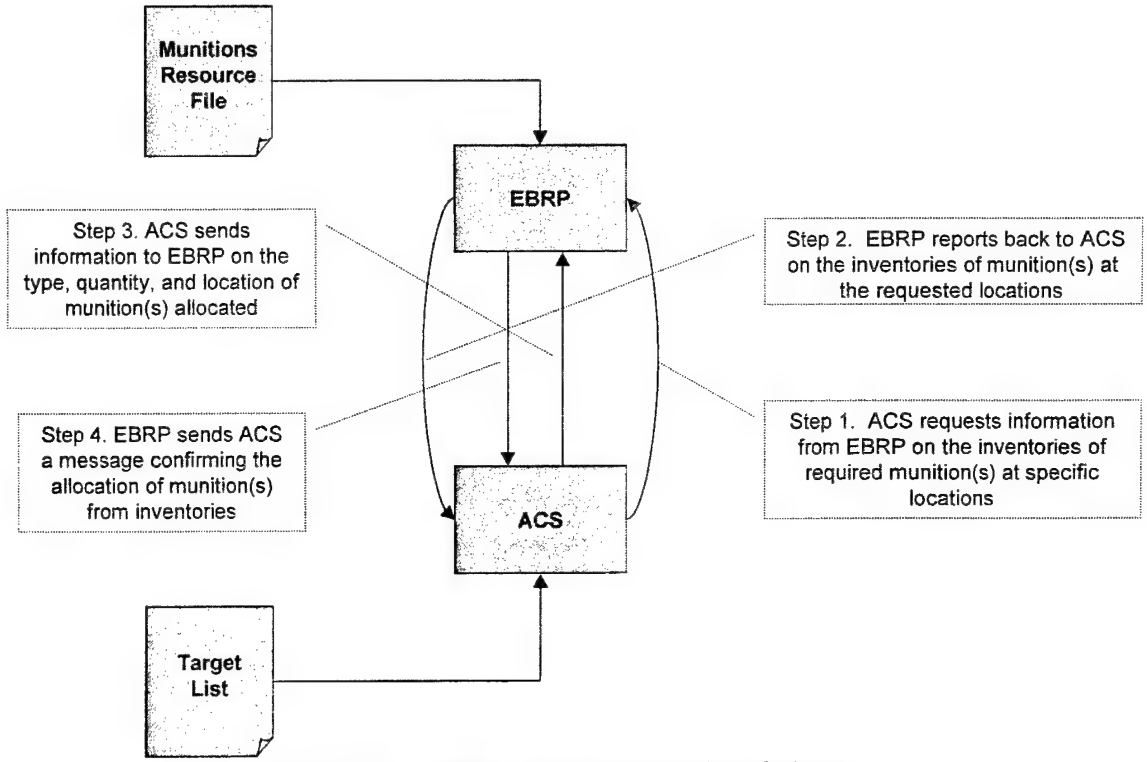


Figure 13. EBRP-ACS Processing Scheme.

8.0 Conclusions

In the future, information dominance will be a decisive factor in quickly defeating emerging targets on the battlefield. Such dominance will require more robust, automated, and dynamic planning processes supported by "netted" systems that utilize agent-based technologies. For instance, in Operation Freedom, over 80% of the targets serviced were "flex" targets – targets not specifically planned for as part of the standard ATO mission planning process. The EBRP demonstration is intended to show how the Cougaar agent-based architecture can be leveraged to help streamline and improve planning and decision-making processes in dynamic operational environments such as those represented by the ATO planning and execution process in an AOC. The demonstration is not intended to imply that an agent based system can, or will replace human planners and decision-makers in this very important process, but rather that agents can play an important role in reducing the cognitive demands placed on humans in highly dynamic and time sensitive environments like a J/CAOC, and improve the speed and quality of the overall planning and decision process.

9.0 References

1. Joint Publication 3-56.1, *Command and Control for Joint Operations*, June 1999.

2. *Effects-Based Resource Planner (EBRP) Concept Paper*, TRS Delivery Order #14 Technical Report, Northrop Grumman Information Technologies, 4 June 2002.

3. Cougaar Developers' Guide, BBN Technologies, Version 9.4, 30 June 2002.

Appendix 1. EBRP Demonstration Data

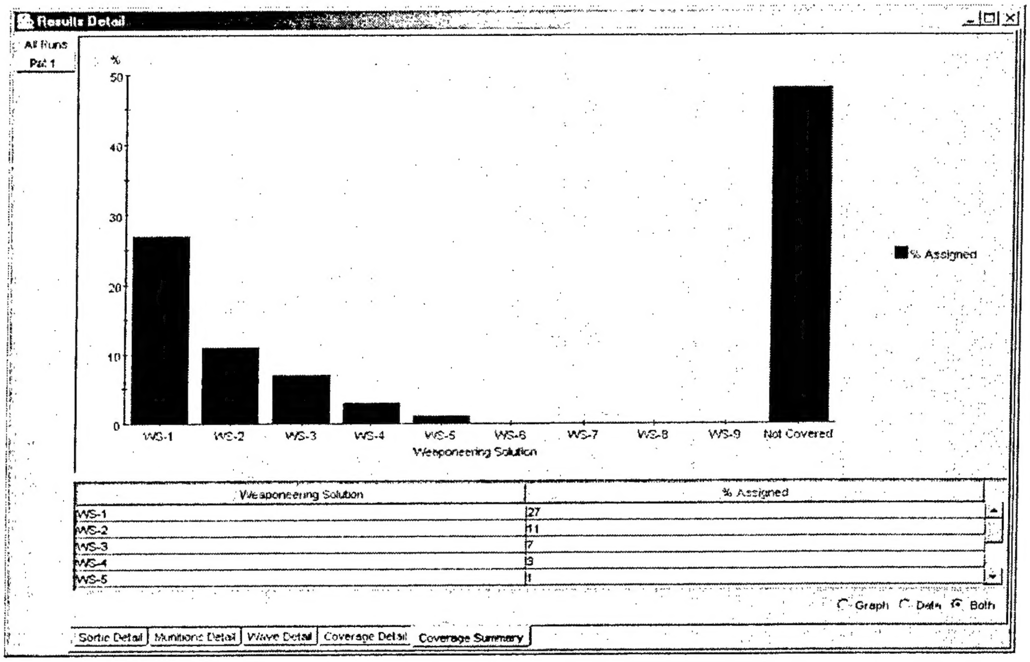
This appendix includes the specific units, beddown locations, and aircraft (type and quantity) that were modeled as part of the EBRP agent society. This beddown information was used to support the development of the EBRP demonstration software and is based on a subset of data from the Pacifica dataset used to support JEFX experiments as well as the EBO research and Cross-Thrust Demonstration.

Unit	Beddown Location	Type Aircraft	Quantity
20FS	Mountain Home	F-16C	12
34BS	Mountain Home	B-1B	6
336FS	Nellis	F-15E	18
391FS	Nellis	F-15E	18
152FS	Nellis	F-16C/G	12
4FS	Nellis	F-16C/G	12
28BS	Nellis	B-1B	6
325BS	Whiteman	B-2	6
20BS	Barksdale	B-52H	6
94FS	Hill	F-22	12
27FS	Cedar City	F-35	12
VMFA323	Harriet Field	FA-18D	12
VMFA232	Harriet Field	FA-18D	12
VMFA332	Richfield	FA-18D	12

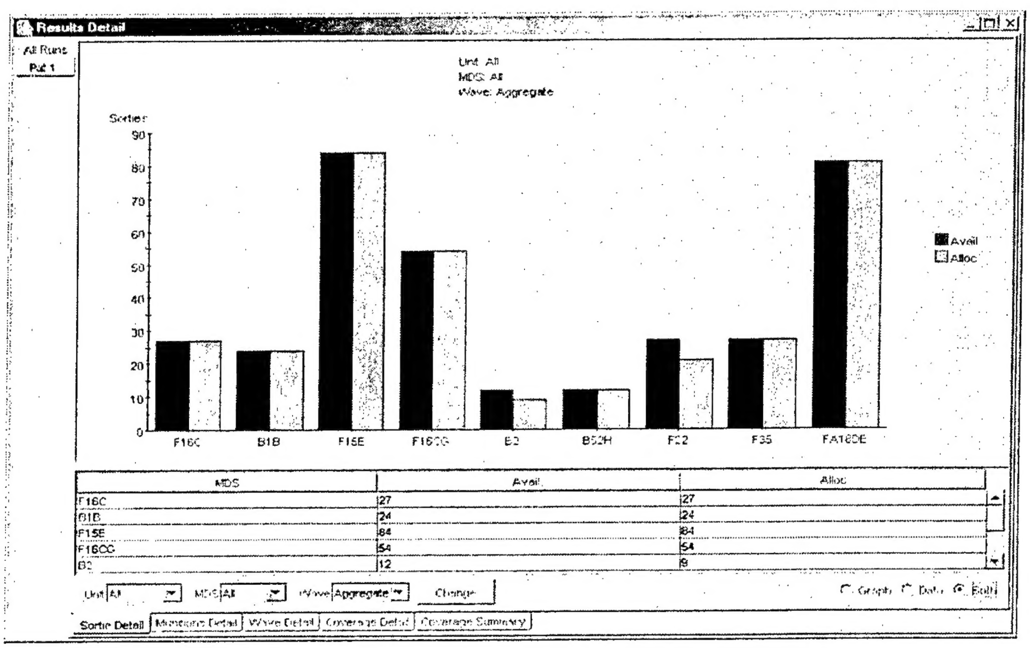
The specific types of munitions modeled at each EBRP beddown location, and the respective quantities used to represent initial inventories can be viewed by location in the EBRP demonstration software.

Appendix 2. EBRP Output Reports

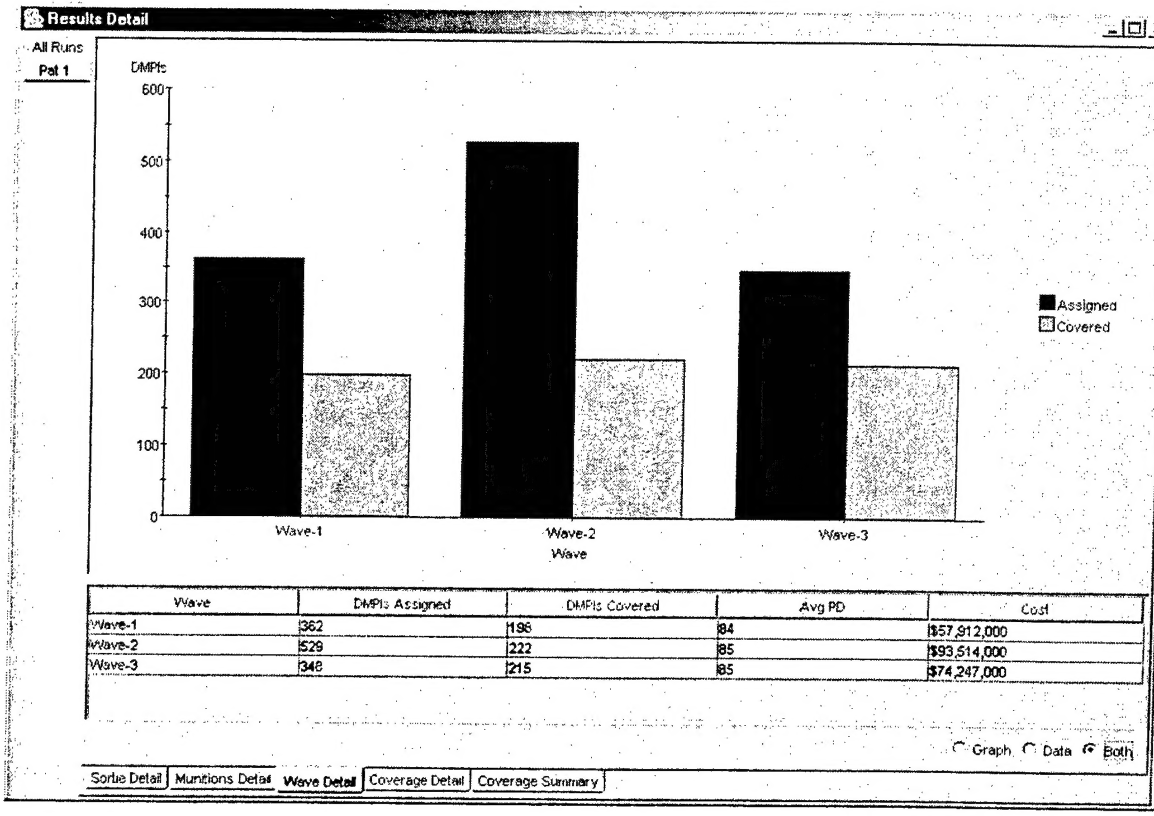
In addition to the summary and detail level target coverage reports, EBRP also provides additional reports on 1) the percentage of DMPIS covered by each ordered weaponeering solution, including the percentage of DMPIs not covered, 2) the allocation of sorties by aircraft type, 3) the number of DMPIs covered in each wave and total cost, and 4) the allocation of munitions by location. Samples of these reports are presented below.



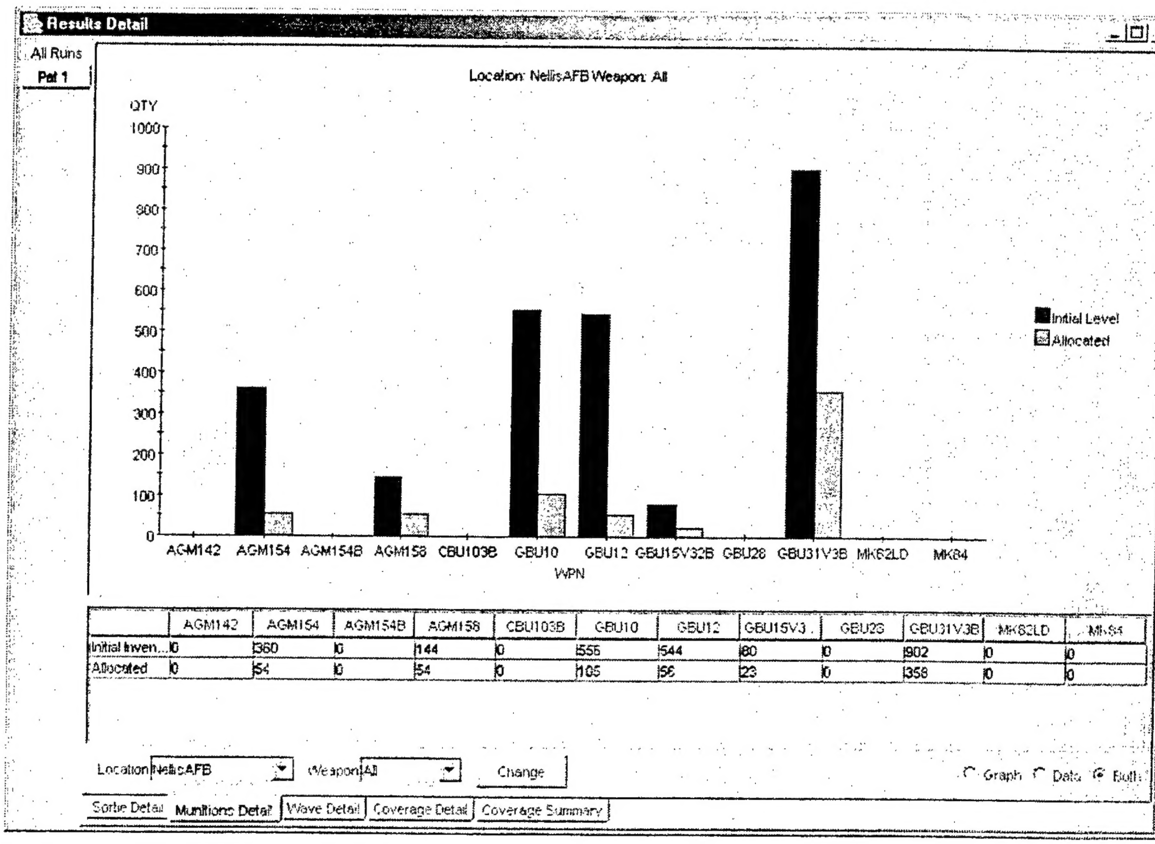
Weaponeering Solution	% Assigned
WS-1	27
WS-2	11
WS-3	7
WS-4	3
WS-5	1



MDS	Avail	Alloc
F16C	27	27
B1B	24	24
F15E	84	84
F16CG	54	54
B2	12	9



Wave	DMPIs Assigned	DMPIs Covered	Avg PD	Cost
Wave-1	362	198	84	$57,912,000
Wave-2	529	222	85	$93,514,000
Wave-3	348	215	85	$74,247,000



	AGM142	AGM154	AGM154B	AGM158	CBU103B	GBU10	GBU12	GBU15V3	GBU28	GBU31V3B	MK82LD	MK84
Initial Inven...	0	360	0	144	0	555	544	80	0	902	0	0
Allocated	0	54	0	54	0	105	56	23	0	358	0	0